Modeling Epidemic Spread in Synthetic Populations — Virtual Plagues in Massively Multiplayer Online Games

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ABSTRACT

A virtual plague is a process in which a behavior-affecting property spreads among characters in a Massively Multiplayer Online Game (MMOG). The MMOG individuals constitute a synthetic population, and the game can be seen as a form of interactive executable model for studying disease spread, albeit of a very special kind. To a game developer maintaining an MMOG, recognizing, monitoring, and ultimately controlling a virtual plague is important, regardless of how it was initiated. The prospect of using tools, methods and theory from the field of epidemiology to do this seems natural and appealing. We will address the feasibility of such a prospect, first by considering some basic measures used in epidemiology, then by pointing out the differences between real world epidemics and virtual plagues. We also suggest directions for MMOG developer control through epidemiological modeling. Our aim is understanding the properties of virtual plagues, rather than trying to eliminate them or mitigate their effects, as would be in the case of real infectious disease.

Author Keywords

Virtual Plagues, Digital Plague, Infectious Disease, Epidemiology, Synthetic Population

INTRODUCTION

A virtual plague is a process in which a behavior-affecting property spreads among characters in a Massively Multiplayer Online Game (MMOG). The MMOG individuals constitute a synthetic population, and the game can be seen as a form of interactive executable model for studying disease spread, albeit of a very special kind. Previous work has shown that sixth grade student players ascribe virtual plagues the same properties as real diseases [13]. Therefore, some players can be expected to try to use their knowledge about disease spread when confronted with a virtual plague.

What makes the virtual plague special is that its initiators (be it a game developer, an individual code developer, or a code logger) do not let any mapping to the real world constrain them. In contrast to computer scientists developing tools for studying epidemiological processes and to the physicians and sociologists using them, the initiators seek to learn little about the real world. They concentrate instead on the virtual world of the game and are happy to make the MMOG more interesting through the particular form of modification (*mod*) that is the virtual plague.

Depending on whether the game data is on the client side or on the server side, virtual plague initiators (a kind of *mod-*

ders) have a relatively easy or hard task, respectively, to implement the mod and to test its effects. Some games, such as The Sims, encourage mods (including virtual plagues) and the game has a huge community of modders. In one famous case, the guinea pig mod [15]; one of the first recorded virtual plagues, the culprit turned out to be the chief game developer Mr. Will Wright himself [10]. This opened for a discussion about the responsibility from the game developer side as to acknowledging the time and effort put in by people into their game characters, including not only virtual plagues but also, e.g., keeping servers alive in spite of declining numbers of players. The very first mods were made by Wizards (and players with access to the underlying text databases) of Multi-User Dungeon (MUD) in the late 1980s [11].

The most famous example of virtual plague initiation from the developer side is perhaps Blizzard's introduction of the Corrupted Blood debuff in World of Warcraft. This debuff was originally conceived of as spreading from monster to player only, although Blizzard let it transmit from player to player if the players were standing close to each other. The idea was to let one boss monster issue the debuff, which would then be allowed to affect all players fighting that particular monster (and ultimately help kill off another boss monster in the same area). What was unexpected, and seemingly a surprise to Blizzard, was that players passed the debuff on to their pets, dismissed the pets, and then resummoned them later, in much more populated areas. This led to tens of thousands of deaths on at least three servers, and caused Blizzard to try to correct the problem through various quick fixes (cf. [16]). The pet debuff trick has analogues in the real world, in viruses spreading between humans via animal reservoirs, for instance. Epidemiologists also showed an interest in the human behavior connected to this virtual plague, e.g., people steering their characters towards large cities to pass on the disease to as many other characters as possible before they died [14].

Another example is the *gray plague* in the game *Kingdom of Loathing* which was initially spread from contaminated *comfy blankets*, no doubt a pointer to the infamous (and some claim deliberate) spread of smallpox to the native Americans in the siege of Fort Pitt in 1763. In the game, the plague spread via the chat and the messaging between the players, regardless of player positions on the map. This has no correspondance to real world spread of disease, but rather to rumor diffusion. Since the chat and the message passing are the main tools for networking, it was a successful channel for spread. After a few weeks, a serum was given to the players in a special quest, which wiped out the plague [9].

To a game developer maintaining an MMOG, recognizing, monitoring, and ultimately controlling a virtual plague is important, regardless of how it was initiated. The prospect of using tools, methods and theory from the field of epidemiology to do this seems natural and appealing. We will address the feasibility of such a prospect, first by considering some basic measures used in epidemiology, then by pointing out the differences between real world epidemics and virtual plagues. We will finally suggest directions for MMOG developer control through epidemiological modeling. Our aim is understanding the properties of virtual plagues, rather than trying to eliminate them, protect individuals, or mitigate their effects, as in the case of real infectious disease. This is in part due to our stance that the effects of a virtual plague are not necessarily unwanted. We will not discuss computer viruses, since these are already well understood, but more importantly they are an example of a virtual phenomenon crossing the bridge to the real world. We therefore stick to the mapping between on the one hand a purely synthetic population subjected to a virtual plague and, on the other hand, a real population subjected to epidemiological studies pertaining only to real disease.

BASIC EPIDEMIOLOGICAL MEASURES

The classical SIR model [1] divides the affected population into three stages: Susceptible, Infected, and Recovered/Removed. It is a top-down macro model based on homogeneous mixing: you essentially throw a population, with relevant distributions, as well as a pathogen and some of its properties, into a bag. Then you shake the bag, and an affected population results. No explicit modeling of space is done, and no outliers (such as super-spreaders) are considered; the model is built on averages, and may be described in its entirety by a set of differential equations.

Micro-models, by contrast, let a set of individuals populate a synthetic landscape, and then execute a simulation run, in which an infectious disease spread pattern emerges. Due to stochastic elements, this pattern varies with each run, and so simulations are often repeated over long series of runs. In particular, many runs might be required before anything interesting happens, since realistic parameters will imply that an epidemic does not actually occur very often. Each individual has a state, i.e. the individuals are agents part of a multi-agent system (cf. [2]). In particular, the state carries information about the progress of the disease in those agents that are affected by the pathogen. The smallpox model of Halloran *et al.* [8] may serve as an example here:

1. Incubating, noninfectious, vaccine-sensitive (first 3 days after infection)

2. Incubating, noninfectious, vaccine-insensitive (remaining 7-11 days)

3. Prodromal, highly infectious (3-5 days)

4. Symptomatic, infectious (10 % of Prodromal stage), withdrawal (over first 3 days out of 14-17)

5. Recovered/removed

These stages of disease were used for each individual in a discrete time microsimulation based on stochastic generation of 2000 individuals, based on US census data. This is essentially a Markov-chain model, typical for simulating epidemic spread bottom-up. Time is crucial, and the most ambitious models of this kind also have an explicit representation of space (see, e.g., [6; 4]). This means that an entirely new level of adequacy with respect to reality can be reached in the modeling, as compared to the classical macro models.

The *basic reproductive rate* R_0 is often used, in macro- as well as micromodels. In spite of its popularity among modelers, it is a problematic semi-formal aggregate measure. Intuitively, it is the average number of individuals directly infected by an infectious case during his or her entire infectious period, when he or she enters a totally susceptible population (see, e.g., [7]).

There are two ways of coding the R_0 of the disease: micro- or macrocoding. In the macrocoding, the rate is set *ex ante*, based on empirical evidence from earlier outbreaks of the disease under study. The R_0 value assignment is complicated by the fact that one may wish to separate first-generation cases from later-generation cases, e.g., by taking the weighted average. The rate is also contingent on the rate of vaccination, further complicating macrocoding. Assumptions of a high rate of vaccination reduce the R_0 value, for instance, but making good guesses about the actual rate of vaccination is difficult, for many diseases.

In the microcoding, R_0 is potentially different in each simulation run and any description of the emergence of the value will be made *ex post*. The purpose of *ex post* descriptions is to verify that the rate does not reach absurd size, or that it does not vary too much between various geographical regions, modulo population density [3].

EPIDEMIOLOGY FOR VIRTUAL PLAGUES

Keeping a virtual plague in check is very different from keeping real infectious disease in check. In particular, it is a lot easier, and most importantly its effects are negligable compared to those of real disease. But there are other intriguing aspects of virtual plagues. They might provide for more interesting game play, but only if they are neither too devastating, nor too easy to fend off. In order to keep virtual plagues active, a macro modeler would say that the R_0 value should be very close to 1. A micro modeler would rather say that the virtual plague should spread at just the right pace, in interesting and unpredicted patterns.

A large number of reasons make micromodeling virtual plagues a better alternative than macromodeling them:

- First, there is no empirical evidence to build on. Earlier outbreaks of the same virtual plague, if they have occurred at all, will either present a solved problem (i.e., the bug has been fixed, or the players know how to fix the problem in-game, e.g., by completing a new quest) or an entirely new problem (i.e., no player will know what to do).

- Second, the (either geographical or virtual) location of players in-game is important, just as in real life epidemics. Even if players can teleport between certain places in certain games, the distance usually yields a constraint for disease transmission which may be modeled in micro, but not in the classical macro models.

- Third, players are heterogeneous. The capability to heal, for instance, varies greatly between players, even within the same vocation. The analogue to real life resistance to a virus, possibly due to a vaccination earlier in life is tempting but unreasonable, since the variance among individuals is much larger than in human populations, for any disease. At any rate, the homogenous mixing utilized in the macro approach will not work well to mirror MMOG spread.

- Fourth, the aims and intentions of the players can not be captured in macro modeling. Since the cost of being infected by a disease in most games is negligible, players happily enough tend to be much more risk averse in

real life than in games. In real life, there are two diffusion patterns that need to be modeled in the case of an epidemic: the diffusion of the disease itself, and the diffusion of information about the disease. These two patterns affect each other. For instance, in real life, people that are aware of the fact that the hospital is a high-risk place to be during an epidemic, will not go there if they catch a high fever, because they might catch a much more dangerous disease if they go to hospital with the intent of being examined by a doctor. In a game, curiosity is likely to instead drive people towards the epicenter of a virtual plague, because that is where the game action currently is. This is precisely what happened in the case of Corrupted Blood, when people gathered in the city of Ironforge, for example. Generally speaking, estimating the effect of high-risk behaviors, such as through logging the actions by super-spreaders, or the intentional spread by so-called zombies, is much easier in micro than in macro.

- Fifth, the ability for virtual plagues to spread through different channels is not easily modeled in macro. However, it may be necessary to be able to model all aspects of the virtual plague in order to understand how to halt its spread. The more channels that the plague may spread through, the harder it is to control it by, for example, limiting the use of a chat, or preventing players from entering a contaminated area in the game.

CONTROLLING THE IMPACT OF VIRTUAL PLAGUES

The impact of a virtual plague on any MMOG is very difficult to control. However, there are a number of possibilities that could be used by developers or that people with server code access could exploit. In the best of all worlds, this leads to a MMOG benefiting from interesting emergent behaviour-changing patterns, from which there is something to be learned for all players affected. If this is to hold true, virtual plague initiators should be aware of a number of possible pitfalls and misconceptions. We try to provide the start of such a catalog here. The items in our catalog can hopefully serve as guidelines for controlling social and even economic effects of badly engineered virtual plagues.

The Initial Phase

The very first days of an outbreak of a potential epidemic are vital to policy makers and epidemiologists studying real disease. This is because the policy measures set in can actually determine whether there will be an epidemic at all. The models for studying initial spread are also different from the models used later, when the disease is a pandemic or is endemic. In the case of virtual plagues, if there is no warning and no information whatsoever about what is going on, players will spread false rumors about the disease. These rumors will propagate quickly, which is not necessarily bad for game play, but will lead to players responding differently to the virtual plague. In the MMOG Tibia, one or more warnings preceed each monster raid, described by game developer Cipsoft as *automated events* [5]. These warnings are different for each of the 60 different raids, sending players to approximately the right place and with approximately the right expectations. Something similar is recommended for virtual plagues. Will players heed the warnings? Not necessarily, but at least the first players encountering the virtual plague will be unfearing high levels, if the information issued is correct.

The Epidemic Phase

Once the virtual plague is past its first days since introduction, some places should be heavily affected and others unaffected. One way of controlling player behavior is to restrict access to heavily hit areas. Players will most likely try and go there in spite of restrictions, creating new areas of intensely populated areas, just outside the restricted area. These are good candidate areas for spreading more information about the virtual plague, as most players will be there with the purpose of finding out more about the disease.

During the period of maximal intensity of the virtual plague, i.e. when the most players are being infected, the adequacy of parameter settings for the individual virtual plague stages will be tested to the full. If for example the incubation period is too long, or if the transmission probabilities are too high, this will show, e.g. through too many players dying or being rendered immobile by the virtual plague (somewhat counter-intuitively possibly leading to it to die off, since there will not be enough new victims for it to spread!). Experimenting with individual costs, e.g., letting individuals be affected differently, either contingent on their state when they contracted the virtual plague, or on stochastic variables, is also important, as it further underlines heterogeneity. For instance, healthy individuals could behave as if they had immunity, as could individuals that have already suffered from the virtual plague at least once. Decisions have to be made about whether or not immune individuals spread the virtual plague, and for how long. In the case of real diseases, the most feared ones are generally speaking those in which victims feel well enough to move around while they are contagious, and get notably sick only in later stages of the disease. Non-immune individuals that have contracted the virtual plague could show this in appearance or behavior, e.g., by moving slower or less, as if "drunk" or as if affected by a spell. This was not carried out to enough extent in the case of Corrupted Blood, which was also much too contagious and arguably much too harmful.

The Recovery Phase

The solution to players combatting a virtual plague could be a virtual cure, the finding of which makes for an excellent quest. Much like the scientific community relatively successfully put aside competition in order to swiftly cooperate to control the real life SARS epidemic, one could wish for players to set aside differences like guild wars and revenge schemes in order to fight this new threat. In this way, a virtual plague could be a bringer of peace to a MMOG. This, however, requires the quest to be specified somehow, at least in the sense that sufficient clues could be obtained before too much suffering from the virtual plague was endured. Introducing a new boss monster would be one example.

The Case of the Gray Plague

As an example of the three phases described above, let us see what happened in the case of the Gray Plague in the Kingdom of Loathing.

The Initial phase The Gray Plague showed its first symptoms in the chat three days after the first players got infected. Someone noticed, and was able to confirm through image analysis in GIMP, that the usually black text in the chat had turned dark gray. A *-cough-* was also added now and then when the infected player chatted.

The Epidemic Phase As the text got lighter and lighter gray, and players also began to shudder, the players looked for
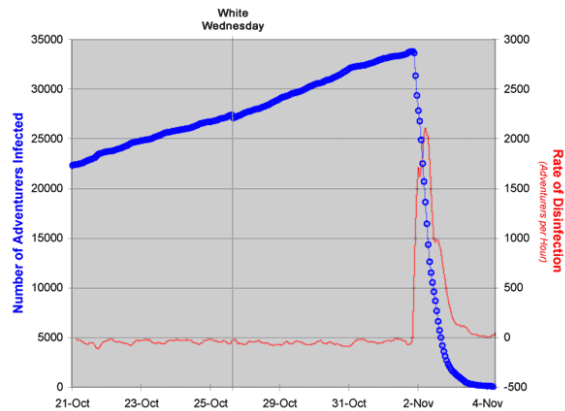
Figure 1: The spread of the Gray Plague in the Kingdom of Loathing.

cures, for instance a pair of rose-colored glasses that made the text look black again to the player. However, the glasses merely took away the symptoms, and the player still infected chat mates. Another attempt was made to use *Doc Galactic's Medical Cure*. It temporarily cured the player, but the player was still susceptible to the plague if it entered the chat again or got in-game messages from infected players. Since there was no coordinated action, the cure was not effective.

The Recovery Phase Finally, the council set up a quest in which the players could get the items needed for making a serum blowgun that made them immune to the gray plague. The plague was more or less wiped out in three days, see Figure 1 [9].

Evolutionary Development

A virtual plague could mutate, like viruses do in the real world. In this way, it could tacitly remain in the MMOG for months or even years, unbeknownst to many players, and then reveal itself, either as a deadly plague, or as something contagious but quite harmless (e.g., producing scars on the avatars, or requiring medicine to regain stats).

Learning from Virtual Plagues

Browsing blogs from the weeks after the Corrupted Blood event, one finds multiple comments worrying about Corrupted Blood being intentionally spread by high-level players, with the malicious intent of studying effects of the virtual plague: The ulterior motive of those players was by the commentators supposed to be the unleashing of a disease in real life, which could be made more devastating thanks to what they learned from the virtual plague. Not only was this not the case with Corrupted Blood, since it was initiated, albeit not entirely controlled at all times, by Blizzard. It is also an unrealistic scenario because of the complexity of the game. If fact, any MMOG is likely to be a much too complex system to allow for studies with implications for real disease. There are several simulation environments that lend themselves to such malicious intent, and even if the community awareness of terrorism and similar serious threats among computer scientists creating these environments is high, terrorists would much more likely try and get their hands on such simulation platforms than manipulating MMOGs. There are, however, a number of properties that can (and in the case of virtual

plagues maybe even should) be shared between real-life epidemics and virtual plagues:

- Both domains need to model individuals situated in an environment that allows for the transfer of the disease between them, subject to constraints coded by various transmission probabilities called BETA-values. Occasionally, the environment itself (in the case of virtual plagues through pets or NPCs, for instance) may host the disease, on its way between two individuals.
- The disease does (in the vast majority of cases) decrease the capabilities of the individuals in some way. A virtual plague may cause the death of a character, which may cause the player much distress, depending on the in game penalty for death (banishment, loss of eq, mana, monetary means, exp, etc.).
- Measures may be taken by the individuals to decrease the risk of being infected.

However, the possibility to handcraft virtual diseases also opens up for new virtual plague designs, violating the classical physical laws that real diseases have to obey. Virtual plagues spread through chat and message channels is one such novel approach that, even though physical contact in the virtual world is avoided, still can be justifiable in the game. Here sociological research into the spread of rumors is more relevant than epidemiology, if scientific explanations of gaming behavior are sought (cf., e.g., [12]).

CONCLUSIONS

We have presented guidelines for controlling, and to some extent for designing, virtual plagues in MMOGs. Microsimulation is currently the only way to adequately model virtual plagues, and we have shown why the suggested use of traditional epidemiological models from the SIR family is inappropriate. The study of virtual plagues is still in its infancy, but if game data is made available this would enable more formal studies of their properties, which vary between different MMOGs. Ambitious micromodels of real infectious disease could be of pivotal importance to such studies.

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